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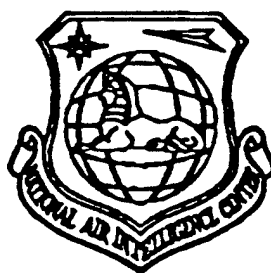
OPTIMIZATION OF LASER RADAR TRANSMISSION ANGLES
UNDER INTERFERENCE CONDITIONS

by

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OPTIMIZATION OF LASER RADAR TRANSMISSION ANGLES
UNDER INTERFERENCE CONDITIONS

Sun Qingguang

ABSTRACT This article describes the current status of the development of laser technology, operating methods associated with laser radar systems, as well as the interference they are subject to. Under these types of interference conditions, optimization of divergence angles is put forward, making use of analyses of expressions obtained for power flow densities. A basis is found for laser radar divergence angle optimization.

KEY WORDS Laser technology Laser radar Laser detection Laser radiation Laser power

1 INTRODUCTION

Following along with the development of laser technology and its day by day improvement, its applications in the military realm are already quite extensive. Development has been done of several types of laser detectors, tracking radars, and different types of laser guided weapons. One of the keys to making use of laser radars to carry out detection of targets, automatic identification, and tracking as well as carrying out guidance is to understand target laser scattering characteristics. Outside China, at the same time as research and development on laser radars and laser guidance, measurements and analysis have also been carried out on target scattering characteristics.

At the present time--at the same time as developing various types of laser weapons systems domestically--there has also been development of research work on laser scattering characteristics of targets. This is primarily aimed at measurements of laser scattering cross sections for targets as a whole. To only make use of high resolution laser radars to carry out target detection, identification, tracking, and guidance is not enough. It is also necessary to carry out research with regard to imagery characteristics of targets as a whole as well as divergence angles associated with irradiation beams. Laser divergence angles are important parameters associated with laser outputs. In the realm of laser technology, a good number of important instruments and equipment are inseparable from them.

On the basis of relevant relationships between radiation divergence angles associated with laser transmission paths and

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external target display errors, it is possible to carry out tracking and observations of entire fan shaped sectors. When the reaction times of these systems are very fast, there is then a requirement for high powers in association with transmission paths and high precisions in external target displays. During the process of analyzing observations of fan shaped sectors, it was discovered that, if divergence angles are very small, there is then a possibility of missing targets. If divergence angles are too large, power flow densities associated with detecting targets will then diminish. If power flow densities decrease to a threshold value, targets will no longer be displayed. As a result, it is necessary to carry out optimized selections of divergence angles. This article will explore several points below associated with divergence angle optimization problems. /180

2 LASER RADAR SYSTEM OPERATING METHODS

Pulse lasers are taken and shot out to act as detection lights. Light scattered (reflected) by detected targets is received, and such information as direction, location, and so on is acquired from return times, scattering intensities, frequency drift, polarization, and so forth.

Measurements associated with target laser scattering imagery generally opt for the use of point to point scanning methods for completion. As far as laser beam point to point sweeps of target surfaces are concerned, measurements are made of laser scattering intensities at various points on targets. Finally, they are formed into complete laser target scattering images. On targets, the measurement results associated with each measurement point can be determined from laser radar equations.

$$I(x \cdot y) = \eta P_0 T^2 \frac{\pi D^2}{4L^2} \sigma(x \cdot y) = K\delta(x \cdot y) \tag{1}$$

In equations, η --quantum yield of detection devices
  P_0 -- laser radiation power
  T -- system transmissivity
  D -- reception aperture
  L -- distance from target to receiving system
  $\sigma(x^e$ y) -- laser scattering cross section associated with irradiated image elements $(x^e$ y).

Through scanning lenses, laser beams are made to scan various image elements point to point. In conjunction with this, measurements are made of scattering signals associated with targets. It is then possible to obtain imagery reflecting target laser scattering cross section distributions. Light sources and detection devices form an independent unit. Transmitted and received signals are coupled together by a polarization beam splitter and transmission/reception optical systems. If light

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sources and detection devices are replaced, it is also possible to carry out measurements with regard to different light sources. This system is controlled by an IBM-PC microcomputer. Besides controlling scanning system operations, it is also capable of completing modulus changeovers, data collection, storage, display, and processing functions. Computers and various parts of systems are linked up with each other through serial ports.   /181

3 INTERFERENCE RECEIVED BY LASER RADAR SYSTEMS

Interference signals are one of the important causes creating an inability in laser radar systems to operate very well. The interference signals can be divided into two types--system internal and external. System internal interference signals are such things as white noise associated with photoelectric detectors, white noise produced by amplifier circuits themselves, as well as interference produced by electric power sources, and so on. External interference primarily refers to interference produced by the environment--for instance, interference produced by electromagnetic sources, radios, radars, electric arcs, background light, lightening, as well as gunfire, and so on.

The different levels of influences on laser radar systems from the interferences described above are also not the same. As far as some interferences are concerned, after adopting certain measures, it is possible to alleviate or eliminate them. Generally speaking--with regard to electromagnetic sources--it is possible to adopt methods associated with electromagnetic shielding, electromagnetic insulation, and elimination of couplings. With regard to external optical source interference, it is possible to opt for the use of narrow band light filters as well as reducing the fields of view of receivers, and so on. There are some strong natural interferences. As far as these are concerned, it is possible to opt for the use of the most primitive and the most thorough going shut off methods in order to avoid them. As a result, in situations in general, laser radar systems are placed in a certain interference environment to operate. Therefore, laser radiation divergence angle optimization problems are put forward under interference conditions.

4 DIVERGENCE ANGLE OPTIMIZATION

In order to study divergence angle optimization, it is necessary to set up cooperative targets. The targets in question are placed under interference conditions in order to calculate target display errors and radiation lateral cross section flux density distributions so as to precisely determine optimum divergence angles for laser radar system detection radiation.

In order to precisely specify maximum optimizations for measurement divergence angles, option is made for the use of target probabilities associated with exceeding power flow density threshold values: $F(I \geq I_n)$.

Threshold values are determined by laser radar reception channel input terminal radiation interference levels. These levels

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take as their basic conditions various types of radiation sources associated with different energy levels. As a result, under interference conditions--going through calculations of interference radiation intensities I_n--it is then possible to precisely determine optimized detection radiation divergence angles. In reality, this is making long ranges L and forming laser lateral cross section radiation power values--that is, realizing $I \geq I_n$. It is then possible to guarantee the realization of orders of laser radiation divergence which are adequately large. External target display error distribution patterns, in a majority of cases, are as in the formula below. /182

$$W_1(P) = \frac{P}{\sigma_l^2} \, e^{-P/2\sigma_l^2} \tag{2}$$

In the equation, σ(illegible) -- is target display linear mean square deviation.

In order to make small angle mean square deviations which are close to linear be consistent with angular mean square deviations, let σ(illegible) $= \sigma_a L$. Target positioning detection radiation flux probability density $W_2(I)$ is determined by a function transformation algorithm associated with [2] for random values. From formula [2] one obtains

$$W_2(I) = \begin{cases} \dfrac{1}{I} \dfrac{a^2}{2\sigma_l^2} \left(\dfrac{Ia^2}{I_0 a_0^2} \right)^{a^2/2\sigma^2} & 0 \leqslant I \leqslant \dfrac{a_0^2}{a^2} \; I = I_m \\ \\ 0 & I < 0, \; 1 > I_m \end{cases}$$
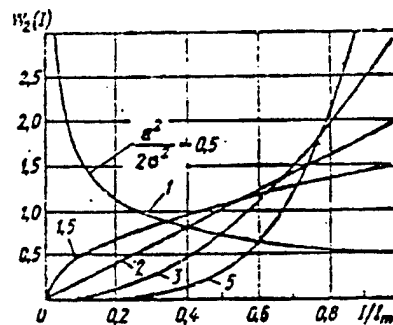

Fig.1

Fig.1 shows a diagram of $W_2(I)$ curves varying on the basis of standard flux density $I = 1/I_m$. These are appropriate for use with different specific values $a/2\sigma_1{}^2$.

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From analysis of curve diagrams, one gets distribution patterns. Specific values of $a^2/2\sigma^2$ should be selected. When $a^2 > 2\sigma i^2$, target displays are high accuracy. In distributions, core positions are in high density ranges. If $a^2 < 2\sigma i^2$, target display precisions are low accuracy, at which time, distribution patterns will give rise to changes. Moreover, in distributions, cores in microflux density ranges produce displacements. When $a^2 = 2\sigma i^2$, distribution patterns will possess forms of equality patterns.   /183

In order to obtain average values associated with distribution pattern target power flow densities:

$$M_1 = a_0^2 I_0 / (a^2 + 2\sigma_i^2) \quad . \quad \text{Moreover, variance}$$

$$\sigma_I^2 = 4\left(\frac{P_0}{\pi a^2}\right)^2 \left[\frac{1}{4\left(\frac{\sigma}{a}\right)^2 + 1} - \left(\frac{1}{2\left(\frac{\sigma_i}{a}\right)^2 + 1}\right)^2\right]$$

In equations, $P_0 = \pi a_y^2 I_0$,   which is transmission channel radiation power.

Following along with increases in target display precisions, target power flow density average values also are on the increase. Moreover, when $\sigma 1 = 0$, with regard to long range detection, option will be made for use of maximum values.

Changes in power flow density variances depend on target variance values and detection radiation beam radii. As far as specific values associated with long distance L detection are concerned, speaking in terms of mean square deviations associated with target power flow densities $(Po/\pi a^2)$, they are also this way.

With regard to different values of power flow average densities which vary on the basis of the ratio σ_1/a, σ_1^2 divergence relationship curves are seen in Fig.2.

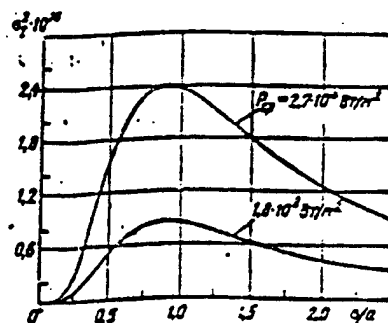Integration patterns associated with target power flow distributions are seen in Fig.3
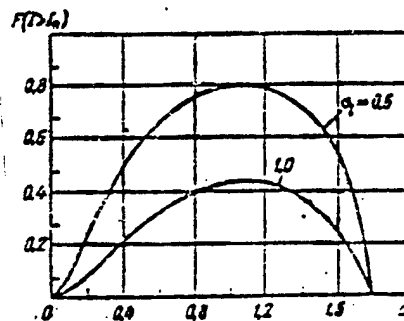

Fig.2

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Fig.3

$$F(I \geqslant I_n) = \int_{I_n}^{a_0^2 I_0/a^2} W_2(I)dI = 1 - (\frac{I_n a_0^2}{I_0 a_0^2})^{a^2/2\sigma_j^2} = 1 - (\frac{\pi a^2 I_n}{P_0})^{a^2/2\sigma_j^2} \tag{3}$$

The integration range associated with equation (3) depends on power flow I. Looking from the angle of physics, the range of changes is capable of being from 0 to $a_0^2 I_0/a^2$.

From the relationship curves in Fig.3, it is possible to see that there exist optimized values a* within radiation ranges. When these values are used to determine σ, P_0, and I(illegible), it is possible to guarantee the optimization of values $F(I \geq I_n)$. Now, taking the characteristics of curves in Fig.3, they are explained as follows. When divergence angles are small values, target beam diameters are also small. Power flow densities are, by contrast, large. However, at this time, due to the fact that target display errors as well as small divergence angle values exist, the probabilities obtained are nothing else than probabilities associated with laser radiation sliding over targets without stopping. When divergence angles increase to very large, laser beam target coverage probabilities also increase. However, target power flow densities decrease by contrast. Moreover, probability increases will make target power flow density threshold values drop.

On the basis of extreme values associated with formula (3), it is possible to obtain an expression for laser beam radiation radii optimization values.

$$a^* = (\frac{P_0}{\pi I_n})^{2} e^{-0.5} \tag{4}$$

In order to detect laser radiation long range divergence curves and detect radiation flux densities, equation (4) is capable of transforming into the form below.

$$(1 + \frac{4L^2}{K^2 a_0^2})^{\frac{1}{2}} = (\frac{P_0}{\pi I_n} e^{-1})^{\frac{1}{2}} \tag{5}$$

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If one introduces $\theta = \dfrac{2\lambda}{\pi a_0}$, then, by (5), it is possible to obtain an expression for optimized divergence angles.

$$\theta^* = \frac{2}{L} \left(\frac{P_0}{\pi I_a} e^{-i} - 1 \right)^2 \tag{6}$$

Under conditions satisfying $4L^2/K^2 a_0^4 \gg 1$, it is possible to simplify it to become

$$\theta^* = \frac{2}{L} \left(\frac{P_0}{\pi I_a} e^{-\frac{1}{2}} \right)^2$$

Fig.4
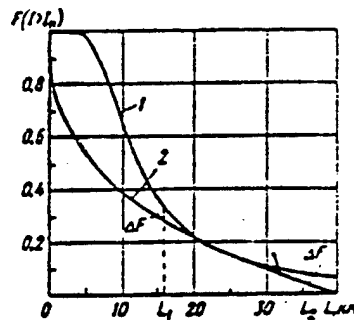
During the formation of optimized divergence angles,

(1)

$\theta = \theta^*$ and $\theta = $ const long range $F(I \geq I(\text{illegible}))$ curves are seen in Fig.4. From the curve diagrams, it is possible to see that the formation of optimized divergence angles, in actuality, can increase probabilities when $I \geq I(\text{illegible})$. At this time, as far as optimized divergence angle probability calculations at 10km long ranges are concerned, $F(I \geq I(\text{illegible}))$ increases 1.6 fold. In conjunction with this, formation values are 0.65. On a foundation of comparisons of probabilities corresponding to different distances $F(I \geq I(\text{illegible})/\theta=\theta^*)$ and $F(I \geq I_0/\theta=\text{const})$, long range precision requirements are determined by Fig.4 curves. Carrying

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out observations with regard to limit values (ΔF), the slope from $F(I \geq I$ (illegible)$)/\theta=\theta^*$ to $F(I \geq I$ (illegible)$)/\theta=$const) is discovered. Then, from the equality $\Delta F=F(I \geq I$ (illegible)$)/\theta=\theta^*)$ - $F(I \geq I$ (illegible)$)/\theta=$const), it is very easy to detect long ranges L_1 and L_2. With regard to L_1 and L_2 correctness equality $\Delta F(L_1) = \Delta F(L_2)$ (see Fig.4). At this time, there is a requirement for target display precisions to be $\sigma_1 = 1/3(L_2 - L_1)$. When ΔF is different values, long range target display precision requirements are seen in Fig.5. From Fig.5, it is possible to see that, as far as increases in target display precisions are concerned, in actuality, they are directly related to extremely long target range reductions. With regard to targets 10km away, target display mean square deviations should not exceed 500-10m, corresponding with the $\Delta F=0.01$ and 0.001.
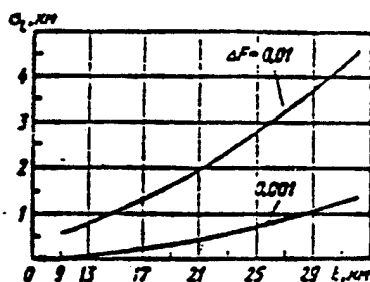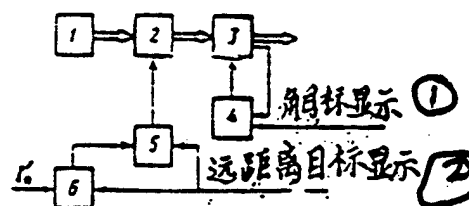

Fig.5

Fig.6 (1) Target Angle Display
(2) Long Range Target Display

Fig.6 is a simplified structural diagram of laser radiation detection divergence angle optimization subsystems. External target display signals are entered into external target display 4 on the basis of bearing and azimuth angle to carry out processing.

This type of processing is capable of clearly indicating optical axis directions associated with transmission signal channels that are mutually adapted to external target display. Long range target displays enter into detection threshold intensity component 6. Moreover, the need to enter into this component is to receive information associated with levels of path interference threat. In conjunction with this, very strong threshold values are formed to enter into detection radiation divergence angle optimization component 5. This 5 is a photoelectric system associated with detection and control signals. These control signals and detection radiation divergence angle optimizations form direct proportions.

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The formation of optimized divergence angles is possible. The distinction between them and optimized angles formed in other systems lies in the criteria associated with control lasers and calculation methods. Moreover, needed control signals are formed.

4 CONCLUDING REMARKS

When external target display system characteristics are fixed, under interference conditions, the formulae which were obtained are capable of guaranteeing the main rationality requirements associated with laser radar characteristics. In the same way, when the characteristic values given for laser radar systems are fixed, it is possible to carry out inverse operations in accordance with the primary characteristics associated with external target display systems.

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